Department of Electrical Engineering

Syllabus for Written section of PhD Comprehensive Examination
(2022 Admission onwards)

The weight age of marks for written section of PhD Comprehensive Examination shall be 40% for core [and 60% for the specialization.

A) Core Section: [Research scholar can select 2 modules out of following 6 core modules as per DC recommendations]

Module Co1: Engineering Mathematics: Systems of linear equations, Eigenvalues, Eigenvectors. Mean value theorems, Evaluation of definite and improper integrals, Maxima and minima, Multiple integrals, Fourier series, Line integral, Surface integral,Volume integral, Stokes's theorem, Gauss's theorem, Divergence theorem, Green's theorem. First order equations (linear and nonlinear), Higher order linear differential equations with constant coefficients, Method of variation of parameters, Cauchy's equation, Euler's equation, Initial and boundary value problems, Method of separation of variables.

Module Co2: Circuits & Networks : Dependent & Independent sources, R, L, C, M elements; Network solution methods, Network Theorems, Transient response of dc and ac networks, Sinusoidal steady-state analysis, Resonance, Two port networks, Three phase circuits, S tar-delta transformation, Complex power and Power factor

Module Co3: Electromagnetics:Coulomb's Law, Electric Field Intensity, Electric Flux Density, Gauss's Law, Divergence, Electric field and potential due to point, line, plane and spherical charge distributions, Effect of dielectric medium, Capacitance of simple configurations, Biot-Savart's law, Ampere's law,Curl, Faraday's law, Lorentz force, Inductance, Magnetomotive force, Reluctance, Magnetic circuits, Self and Mutual inductance of simple configurations.

Module Co4: Electrical Machines & Transformers:Electro-mechanical energy conversion principles; DC, Three-phase induction and Synchronous machines: Types, Configuration, Construction, Starting & Operation, Speed control, Testing & Performance Characteristics,Applications, losses and efficiency, Energy conservation Special machines: Stepper motor, Hysteresis motor, BLDC, SRM, PMSM.

Transformer: Types, Configuration, Construction, equivalent circuit, phasor diagram, Tests & Characteristics, regulation and efficiency;Parallel operation Energy conservation, Auto-transformer.

Module Co5: Measurements,& Instrumentation: Bridges and Potentiometers, Measurements of electrical parameters; Instrument transformers, Digital voltmeters and multi-meters, Phase, Time and Frequency measurement; Oscilloscopes, Error analysis.

Module Co6: Analog and Digital Electronics: Diode circuits: clipping, clamping, rectifiers; Amplifiers: biasing, equivalentcircuit and frequency response; Oscillators and feedback amplifiers; Operational amplifiers: characteristics and applications; Passive & Active Filters, Butterwoth, VCOs and timers, combinational and sequential logic circuits, multiplexers, demultiplexers, Schmitttriggers, sample and hold circuits, A/D and D/A converters. Quantization.

B) Specialization Section: **[Research scholar can select 3 modules out of following in a within or across stream as per DC Recommendations]**

Control Systems stream

Module CS1: Mathematical modeling and representation of systems, Feedback principle, transfer function, Block diagrams and Signal flow graphs, Transient and Steady-state analysis of linear time invariant systems, Stability analysis using Routh-Hurwitz and Nyquist criteria, Bode plots, Root loci, Lag, Lead and Lead-Lag compensators; P, PI and PID controllers

Module CS2: State space models of linear systems - Explicit solutions to linear differential equations, solution to LTI systems, solutions to homogeneous and non-homogeneous cases - Computation of matrix exponentials – Equivalent state space models: similarity transformations, canonical forms, zero state equivalence - Controllability and Observability of LTI systems - Controllable and reachable subspaces - Physical examples and system interconnections - Reachability and controllability Gramians - Controllabilty matrix, Eigen vector test for controllability, Lyapunov test for controllability - Controllable decomposition and block diagram interpretation - Stabilizable system: Eigen vector test for stabilizability, Popov- Belevitch_Hautus (PBH) Test for stabilizability, Lyapunov test for stabilizability.

Module CS3: Feedback stabilization based on Lyapunov test - Unobservable and unconstructable subspaces: Physical examples, observability and Constructability Gramians, Gramian based reconstruction – Duality - Observable decompositions, Kalman decomposition theorem - Detectability, detectability tests - Stability - Internal or Lyapunov stability, Lyapunov stability theorem, Eigenvalue conditions for Lyapunov stability - Input-Output stability: BIBO stability, Time domain conditions for BIBO stability. Frequency domain conditions for BIBO stability - Stabilization by output feedback – Eigenvalue assignment by output injection – State feedback for stabilization and control – State estimation and observer design.

Module CS4: Discrete time system representation –Sample & Hold-Mathematical modeling of sampling process – Data reconstruction- Selection of ADC and DAC- Choice of the sampling period – Prefilter/Antialiasing filters -Effects of quantization errors - Phase delay introduced by the ZOH-Sampling period switching - Modeling discrete-time systems by pulse transfer function -Revisiting Z-transform - Mapping of s-plane to z-plane -Pulse transfer function - Pulse transfer function of closed loop system - Sampled signal flow graph -Stability analysis of discrete time systems -Jury stability test - Stability analysis using bi-linear transformation

Module CS5: Characteristics of nonlinear systems – examples of systems exhibiting nonlinear phenomena- second order nonlinear autonomous systems- vector field representation- classification of equilibrium points – qualitative behavior near equilibrium points- limit cycles – existence of periodic orbits- Poincare Bendixon criterion- analysis of systems with piecewise constant inputs using phase plane analysis - Lyapunov stability theorem for nonlinear systems

Instrumentation & Measurements stream

Module IM1 **Measurements and Instrumentation**

SI Units, significant digits. Errors in Measurements – Systematic and random errors, propagation of errors. Analog Indicating Instrument – The PMMC meter - The PMMI meter – Analog wattmeter. Measurement 3-phase power – 3 wattmeter and 2 wattmeter method. Measurement of small and large resistances using VI method. Measurement of high voltage and high current using resistive dividers –Digital methods of measurement – The counter-timer – time & frequency measurement. Graphical methods of measurement – CRO, DSO Null balance method – Potentiometers – dc and ac Null Balance methods – Bridges dc and ac Voltage and current scaling – CT/ VT and CVT PC based measurement techniques

Module IM2 **Analog Circuits**

Ideal opamp: Linear circuits: integrator, practical integrator, buffer, inverting, non-inverting, differential and instrumentation amplifiers, current sources floating and grounded loads. Real opamp performance parameters. Switched-capacitor circuits, Non-linear & positive feedback circuits - Comparators, Schmitt trigger, precision rectifier, log/antilog amplifiers, analog multipliers. Oscillators – Basics of relaxation oscillator & harmonic oscillators. IC555 timer circuits - Astable and Monostable Multivibrators. Basics of active second order low pass, high pass, band pass and band reject filters. Analog-digital Converters (Flash, Integrating, Successive approximation), Digital to Analog Converters (Weighted resistor and R-2R type). Voltage regulator – shunt type with high current capacity.

Module IM3 **Transducers**

Transducers and their characteristics: Definition of terminologies – Generalized performance characteristics – range – resolution – linearity – accuracy – precision – static and dynamic – rise time – fall time – settling time– slew rate – frequency response – bandwidth; Classification of transducers – active – passive; Types of transducers: Resistive Transducers: Resistance potentiometer – noise – resolution – signal conditioning – strain gauges – basic signal conditioning circuitry – temperature compensation – torque and pressure measurement using strain gauges – resistive temperature device (RTD) – three-lead arrangement – thermistors – linearization - measurement of direction of flow Inductive Transducers: Self-inductance transducers – sensitivity and linearity – signal conditioning circuits – linear variable differential transducer (LVDT; Capacitive Transducers: Single – push-pull – angle transducer – Principle of a humidity sensor – parasitic effects – solutions – signal conditioning circuits.

Power Systems stream

Module PSI: Power System Modelling and Analysis

Modelling, Characteristics and Performance of Power System Components, Load Flow Studies, Symmetrical and Unsymmetrical Fault Analysis, Active and Reactive Power Control, Complex power transfer in power systems, Stability of Dynamical Systems, Transient Stability, Equal Area Criterion, Critical Clearing, Numerical Integration Method, Small Signal Stability, Eigen Value Analysis, Voltage Stability, P-V Curve, Q-V Curve

Module PS2: Power System Operation and Control

Economic Dispatch, Unit Commitment, Optimal Power Flow, Hydrothermal Scheduling, Load Frequency Control, Automatic Voltage Regulator, MVAR Control

Module PS3: Power System Protection

Philosophy of protection, Basic principle and operation of relay and circuit breaker, Overcurrent protection, Directional Relaying, Distance Relaying, CT and CVT response, Transformer protection, Differential protection of Line, busbar, Generator and motor

Power Electronics stream

Module PE1: Single Phase Rectifiers: Half Wave and full wave uncontrolled, half controlled and fullcontrolled rectifier with R, RL, RLE loads, with Freewheeling diode. Input Side Current Harmonics and Power Factor. Filter design for single phase and three phase uncontrolled, half controlled and full controlled rectifiers.

Module PE2: Basic Concepts. Single Phase Inverters. PWM Principles. Sinusoidal Pulse Width Modulation in Single Phase Inverters. Choice of carrier frequency in SPWM. Spectral Content of output. 3 rd Harmonic injection to enhance the source utilization. Bipolar and Unipolar Switching in SPWM.

Module PE3: Three Phase Inverters -Three Phase Square Wave /Stepped Wave Inverters. Three Phase SPWM Inverters. Choice of Carrier Frequency in Three Phase SPWM Inverters. Output Filters. DC Side Current. Space Vector Modulation for three phase inverters- calculation of dwell time, identification of sectors.

Module PE4: DC-DC converters – Design of DC-DC converter for PFC. Dual active bridge dc-dc converter-

Phase angle control for power transfer, application of DAB for battery chargers.Multi-Level Inverters of Diode Clamped Type and Flying Capacitor Type and suitable modulation strategies - Cascade Type Multi- level inverters

Module PE5: Buck, Boost, Buck-Boost SMPS Topologies - Basic Operation - Waveforms - Modes of operation CCM, DCM and BCM. Need for & advantages of employing a high frequency isolation transformer in SMPS designs – Single-ended Forward Converter – need for tertiary winding – effect of leakage inductance on input-output relation of Forward Converter – Double-ended Forward Converter

Industrial Power and Automation stream

Module IPA1 Process Control and Automation : Mathematical modeling and representation of controlsystems - Feedback principle and closed-loop control - Transfer functions and block diagrams - Stability analysis - Bode plots and root locus analysis - PID controllers and compensator design Introduction to process control and automation - Distributed control systems (DCS) and supervisory control and data acquisition (SCADA) systems - Process instrumentation and sensors - Process modeling and simulation - Advanced control techniques (e.g., model predictive control, adaptive control) - PLC architecture and components - PLC programming languages (e.g., ladder logic, function block diagrams) - HMI design principles and Guidelines

Module IPA2 Embedded System and IoT: Embedded system design process and constraints - Microcontrollers and Programming Techniques - Microcontroller architecture and features - IoT architecture and system components - Real-time considerations and interrupt handling - Device drivers and peripheral interfacing - Sensors and transducers for data acquisition - Interfacing techniques for integrating hardwareand software components - IoT Communication protocols for data exchange - Bus architectures: I2C, SPI, CAN, USB - Communication Protocols in Embedded Systems - Cloud platforms and services for IoT applications

Module IPA3 Industrial Drives and Control : Overview of drive systems and their applications - Classification of drive systems based on motor types and control techniques - Key components and their functions in drive systems - Principles of operation for various types of electric motors (DC, induction, synchronous) - Motor characteristics, torque-speed curves, and performance parameters - Power electronics converters for motor control: inverters, choppers, and variable frequency drives (VFDs) –open loop and closed loop speed control - Advanced control techniques: vector control, direct torque control (DTC), Field Oriented Control (FOC)

Module IPA4 Instrumentation and sensors ; Industrial measurement systems – Functional elements of an instrument – Input-Output configuration of measuring instruments - Calibration - Generalized performance characteristics – static characteristics – Measurement of Pressure, temperature, etc. - Industrial signal conditioning systems- Amplifiers – instrumentation amplifiers, Filters, voltage–current converters, voltage-frequency converters

Module IPA5 Industrial Robotics: Introduction to industrial robots and robot classifications - Robot kinematics and dynamics - Forward and inverse kinematics - Robot programming and control - Robot sensors and vision systems - Robot safety and industrial standards

Biomedical and Signal Processing stream

Module BSP1: Cognition and its computation

Part 1 : Anatomical Structures of the Brain - Single neuron level measurements - Single Neuron Imaging and Manipulation of Neural Activity - Synapse and Synaptic Transmission - Synaptic Plasticity - Short Term Plasticity and STDP

Part 2 : Sensory Circuits: Visual - Sensory Circuits: Auditory - Sensory Circuits: Somato sensory - Sensory Circuits: Olfactory and Gustatory

Part 3 : Reward Circuits - Executive Circuits - Alerting Orientation and Executive Network - Disorders of Attention-Basics of Perception Object, Depth and Movement - Neurobiology of attention, Working Memory

Part 4 : Learning Processes – Memory - Learning Disorders - Different types of Plasticity - Developmental Plasticity/ Learning/ Critical Period - Examples of Disorders in Plasticity

Module BSP2: Deep Learning

Part 1: Biological Neuron - Motivation from Biological Neurons - McCulloch Pitts Neuron, Thres holding Logic –Perceptrons - Error and Error Surfaces

Part 2 : Perceptron Learning Algorithm - Proof of Convergence of Perceptron Learning Algorithm - Sigmoid Neuron - FeedForward Neural Networks - Back propagation

Part 3: Basic concepts of Gradient Descent (GD) - Momentum Based GD - Nesterov Accelerated GD - Stochastic GD – Ada Grad - Eigen values and eigenvectors - Eigen value Decomposition –Basis

Part 4: Principal Component Analysis and its interpretations - Singular Value Decomposition - Auto encoders and relation to PCA - Regularization in auto encoders - Denoising auto encoders - Sparse auto encoders

Module BSP3: Biomedical Signal Processing

Part 1: Action Potential and its generation - Origin and characteristics of basic biomedical signals – Electrocardiogram (ECG), Electroencephalogram (EEG), Electromyogram (EMG), Phonocardiogram (PCG), Electroneurogram (ENG), Event-Related Potentials (ERPs) - Sampling and quantization of biomedical signals – Various artifacts including interference from other physiological signals and their removal – Filtering in biosignals: Application of FIR and IIR filters in biosignal processing.
Part 2: ECG processing: 12 Lead system for ECG aquisition - ECG signal from various lead configurations – frequency spectrum of ECG – QRS detection algorithms – use of moving average filter – Cardiac abnormalities and their interpretation from ECG – Long term ECG monitoring – Heart rate variability – ECG data compression.
Part 3: EEG processing: EEG generation – EEG aquisition system – frequency spectrum of EEG – identification of various conditions – sleep, epilepsy, tumour, brain death from EEG – Noise removal from EEG - Features of evoked potentials.
Part 4: EMG processing: MUAP and CMAP, Myoelectronic control of prosthesis. Automated analysis of BP and respiratory waveforms, Biotelemetry.

Module BSP4: Biomedical Instrumentation
Part 1: Fundamentals of medical instrumentation, Physiological systems of body, Features of action potentials, Sodium-Potassium pump, Goldman Hodgkin Katz equation, Monopolar and bipolar recording of biomedical signals
Part 2: ECG – Cardiac Vector – Einthoven's triangle – 12 lead systems – cardiac pacemakers– defibrillators – EEG: Electrical activity of neurons - 10-20 electrode system – advancements in EEG acquisition systems. EMG acquisition – types of EMG electrodes and their placement – applications of EMG
Part 3: Blood flow meters – electromagnetic and ultrasonic blood flow meter. Blood pressure measurement – Korotkoff's sound method – ultrasonic doppler shift method. Oximetry – ear oximeter – pulse oximeter. Spirometry – pulmonary function analyzers –ventilators.
Part 4: Lasers in medicine – CO_2 and argon lasers. Biomedical Ultrasound – various scan modes. X-ray machine – X-ray applications. Bladder and Deep Brain Stimulators. Linear Accelerator Machine for radiotherapy. Overview of MRI.

High Voltage Engineering stream

Module HVE1 **High Voltage Engineering** : Generation of High voltages, AC voltages: Testing transformers-Series resonance circuits; DC voltages: symmetric and asymmetric voltage doubler circuits- Generation of switching surge voltage and currents. Simulation of AC, DC and Impulse Voltage/Current generation circuits. Measurement of high voltages: Sphere gaps, factors affecting sphere gap measurements, correction factors. Measurement of high AC voltage: Capacitance voltage dividers Measurement of transient currents: Resistive shunt, Magnetic coupling, Hall Effect current transducers, Integrating and differentiating type Rogowski coils. Digital techniques in HV measurements

Module HVE2 **Computational Electromagnetics** : Electric and magnetic fields - Maxwell's equations ,Laplace, Poisson and Helmholtz equations Finite element method (FEM)- Differential/ integral functions, Variational method ,Energy minimization, Discretisation, Shape functions ,Stiffness matrix ,3Dand 2D planar and axial symmetry problem.

Module HVE3 **Physics Of Dielectrics** : Dielectric polarization under static fields-electronic, ionic and dipolar polarizations-behavior of dielectrics in alternating fields, nonlinearity between D and E,complex dielectric constant, dissipation factor- Dielectric Formalism- Equivalent circuits-intrinsic dielectric strength- mechanisms of electrical and thermal breakdown in solids-Phenomenological theory of ageing, mechanisms of ageing under electrical, thermal and combined stresses- Accelerated ageing tests-Statistical models for Insulation failure, ageing data analysis- Effect of moisture on cellulose aging.

Module HVE4 **Condition Monitoring Of Power Equipment** **:** Dielectric Response Measurement: Polarization Mechanisms in Dielectrics-Dielectric Response in Time-Domain- Polarization and Depolarization Current (PDC) Measurement-test set up and typical results-Recovery Voltage Measurement (RVM) fundamentals, RVM Spectrum, typical RVM results-Dielectric Response in Frequency-Domain, partial discharge measurements, electrical method, apparent charge-HFCT and Rogowsky coil-acoustic method.

Electric Vehicle stream

Module EV1 Sensors for EV System **:** Review of functional blocks of measurement System-Principles of sensors and transducers –Linearity-Dynamic characteristics - Speed measurement - Hall current sensors and current sampling - Optical tachometer, Acceleration measurement, velocity sensor - Sensor data management, data processing, error estimation. Direct and indirect measurement - capacitive level sensors, optical level sensors, conductivity level sensor, vibrating sensor, Analog and Digital filter design.

Module EV2 Energy Storage Systems for Electric Vehicle**:** Introduction to Energy Storage Requirements in Electric Vehicles - Different types of energy storage; Mechanical: Flywheel based energy storage; Chemical: Hydrogen production and storage; Electrical: Capacitors for EV, Super Capacitor, EDLC; Electrochemical: fuel cell, Battery technology, Type of battery: Selection of battery cell and types, Depth of Discharge (DoD), State of Charge (SoC), Cycling rate (C-rate), voltage of cell, Specific energy, Charge and Discharge rate, Cycle life.

Module EV3 Vehicle Dynamics**:** Basics of engineering mechanics and dynamics: Free body diagrams-Newton's laws of motion- law of friction- Rolling friction-Static loads in vehicle - Dynamic loads during braking: Braking performance- brake distribution between front and rear wheels- Suspension systems: Basic suspension systems- independent suspensions-vehicle modeling with single degree of freedom model - active and semi active suspension systems-wheel steering systems- Motorcycle dynamics: Modeling of two wheelers-loads on wheels- forces acting on motor cycle- suspension.

Module EV4 Electric Power Train: Drives and Control: Tractive effort in normal driving, Energy consumption concept of Electric Drive Trains and its Architecture-Electric Propulsion unit. Si, SiC, GaN devices-based power converters - Distribution of electric power in DC-DC, AC-DC, DC-AC converters used in EV drives. Various Hybrid/EV architectures, various switched mode DC/DC converters for EV drive. Bidirectional DC-DC Converters, effect of parasitic elements, performance analysis, controllers design for DC-DC converters, PWM Techniques- closed loop control of drives - Drive efficiency-BLDC drives-various speed control strategies.

Module EV5 Electric Vehicle Charging and Policy: Classification based on penetration level. General safety requirement for electric vehicle charging stations: IS/IEC 62305. Types of charging stations and Charging Infrastructure, Battery Swapping Station, Move-and-charge zone. AC charging and DC charging - EVSE technical specification and charging time calculation - AC Pile Charger, DC Pile Charger. Earth protection system for charging stations – Fire & safety aspects of charging stations. Selection of EVSE Communication Protocol - Communication gateway - IoT based communication supporting systems for performance measures of EVs. Standardization in e-mobility, Government policies: standards and regulation.